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Title: High-Intensity Linear Accelerator with Ribbon Beam

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Objective

We propose a solution of the fundamental problem in accelerator physics: significant increase of peak beam power in linear accelerator with conservation of beam brightness. It is of primary importance for operation of existing high-power accelerators (LANSCE, Spallation Neutron Source), for development of the next generation of high-power accelerators for basic scientific research and Accelerator-Driven Systems applications (Transmutation of Waste, Nuclear Reactor-Driver), and national security applications, which are all $1B-class facilities. The concept utilizes acceleration of beam with ribbon geometry instead of traditional circular beam. High value of beam current is reached using large width of the beam. Acceleration and focusing is achieved using alternative-focusing principle, which does not require traditional focusing elements (quadrupoles, solenoids). The concept utilizes advantage of 2D plane geometry which excludes beam distortion along beam width and results in conservation of high-value of beam brightness.

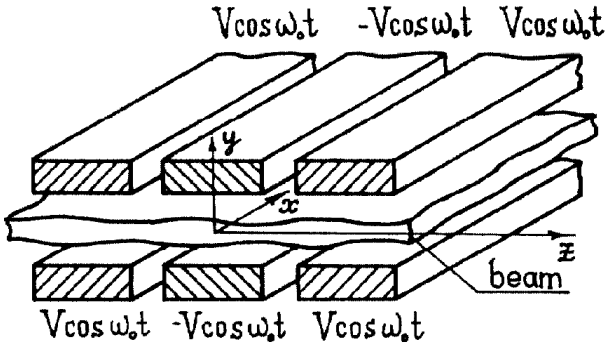

Fig. 1. Schematic representation of RF accelerating channel with a ribbon beam.

Innovation and Potential for Transformational Impact

One of the main trend in accelerator physics and technology is development of high-power high-intensity proton and H^- ion linear accelerators. Los Alamos Accelerator Facility was the first world-class accelerator with average beam power of 1 MW. Spallation Neutron Source accelerator facility in Oak Ridge currently delivers beam with power of 1.4 MW. European Spallation Neutron Source is the next level of high power accelerator with expected beam power of 5 MW. New projects like Accelerator Driven Systems (ADS) require increase of beam power up to 10-15 MW.

Design of new class of intense linear accelerators requires achievement of high peak beam current and high beam brightness with high beam reliability and minimized power consumption. Simultaneous achievement of combination of all parameters meets serious technical difficulties. Increase of beam intensity is accompanied with degradation of beam brightness due to multiple nonlinear phenomena in beam. Maximum peak current of 100-150 mA that can be accelerated in conventional accelerating structures is limited by space charge repulsion of particles within the beam. Another serious limitation of beam intensity is related with formation of beam halo which degrade accelerator components and therefore reliability as well as hinder or prevent hands-on maintenance. In the past, it has been a subject of long-term study for different projects including accelerator transmutation of waste (ATW), accelerator-based conversion of plutonium (ABC), accelerator production of tritium (APT), and the development of next-generation accelerator-

driven spallation neutron sources [1]. Presently, beam halo limits the increase of power of accelerated beams in existing accelerators (LANSCE, SNS) [2], and creates problems with operation of superconducting cavities. Much of the beam loss is due to the formation and interception of a low-density beam halo at a large radial distance (4 or more times the rms beam radius) from the beam core. Modern projects using high-intensity accelerators with final energies of 1-1.5 GeV require keeping the beam losses at the level of 10^{-7}/m to avoid activation of the accelerator and allowing hands-on maintenance over long, extended operating periods.

In order to significantly increase beam current and minimize beam halo creation, we propose acceleration of ribbon beam in RF system (see Fig. 1). Higher beam intensity (up to 1 A) is achieved through enlarging of beam cross section. Uniform structure along the width of the beam results in minimization of beam distortion. Ribbon beam concept is used in electron optics and RF generators to increase beam intensity, but have not been used in ion accelerators. There is no complete understanding of possibilities and limitations of this approach for increasing capabilities of linear ion accelerators. Several methods have been proposed for acceleration and focusing of ribbon beam. In Ref. [3] acceleration of ribbon beam was considered in drift tube linear accelerator utilizing alternative-phase focusing principle. Variation of synchronous phase from one RF gap to another one creates stability in longitudinal and vertical directions, however does not provide stability along the width of the beam. In Ref. [4] it was proposed to use undulator field to create transverse focusing in both directions. No data on accelerator acceptance, current limits, and accelerating gradient have been obtained so far. The present work is focused on development of expertise of ribbon beam acceleration, and evaluation of potential of this method for high-power accelerator applications.

Relevance and Leadership Potential

LANL has been a world leader for decades in the development of high-intensity accelerators with suppression of halo formation and beam emittance growth. The proposed project is a continuation of these long-term LANL efforts in innovations in beam physics and accelerator technology. A breakthrough in increase of beam intensity with halo suppression and emittance growth is needed to significantly improve present operation of powerful accelerators (LANSCE, Spallation Neutron Source), and to develop technology and expertise for future projects. The proposed study of beam physics enhances LANL and AOT-Division accelerator science capabilities. Multiple international projects will benefit from this study including the European Spallation Source in Sweden [5], the J-PARC Accelerator Facility in Japan [6], upgrade of the ISIS accelerator complex at RAL in UK [7], and the design and operation of the multi-purpose irradiation accelerator facility MYRHHA in Belgium [8].

Research Approach

We expect to perform an analytical and numerical study of the proposed accelerator concept with development of model for RF structure and perform simulation of beam dynamics. Members of the project team from LANSCE have necessary expertise to accomplish the proposed project with sufficient skills in beam physics and numerical simulations. Appropriate combination of codes (CST Particle Studio, Beampath, Superfish) allows us to perform numerical study of the ribbon beam dynamics concept, complete a 3D electromagnetic modeling of RF structure and 3D beam dynamics study including space charge forces. As a result of study, we anticipate creation of physics theory of ribbon beam acceleration and working model to demonstrate possibilities of the method.

References

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